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An Agent-Based Model for Determining the Agriculture Demand Based on Farmers' Socio-Economic Characteristics

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Abstract: Modelling and presenting mathematical relationships for human behaviour is one of the most complex issues that researchers have always dealt with. In this article, a bottom-up framework for calculating agricultural needs is presented using the socioeconomic characteristics of farmers (such as education level, age, and dependence on income on agriculture) and how their lands are located concerning each other (interactions between neighbours). The objective function of this framework is to maximize the profit of individual farmers based on the amount of water received. Two scenarios, ABM1 (not considering neighbourhood effects) and ABM2 (all cases of farmers' placement and feeling neighbourhood effects), were investigated. In the first scenario (ABM1), there was a noteworthy reduction in water deficit volumes by approximately 35%, accompanied by a 20% increment in farmers' profits. Interestingly, higher risk-taking tendencies correlated with reduced profit margins. The second scenario (ABM2) underscored the significant role of neighborhood dynamics in cultivating diverse behavioral patterns among farmers, subsequently affecting their profitability. A granular examination revealed that farmers with a higher propensity for risk-taking generally accrued lower profits. Additionally, the study facilitated the calculation of total annual profits and average water consumption for each farmer, offering valuable insights for optimizing water resource management and allocation strategies. These findings are instrumental for planners and water resource managers aiming to promote sustainable agricultural practices and efficient water use.

Keywords: agriculture demand; Standard Operating Policy; agent-based model; agricultural risk

1. Introduction

The lack of water in the last few decades has made the water supply issue one of the main limiting factors in the comprehensive development of watersheds now and in the future. In the meantime, the agricultural sector is considered the leading consumer of water resources, consuming the most extractable water [1,2]. Understanding farmers' behavior may offer assistance to diminish existing pressures on water assets and increment sustainability and versatility to climate change [3,4]. So far, many m have been done regarding the models of water allocation to farmers, which can be referred to as Systems Dynamics (SDs) models [5,6], allocations based on game theory [7,8], allocations based on single or multi-objective optimization algorithms [9–12], and DPSIR models [13,14]. Each of these methods has specific limitations and strengths. The purpose of this article is to present a behavior model of farmers based on the amount of available water.

Agent-Based Model (ABM) is a relatively new approach to modelling systems composed of independent but interacting factors. Engineering and management sciences jointly seek to model the real world to describe, understand and manage phenomena, with the difference that engineering

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sciences model natural world phenomena and management sciences model human systems [15,16]. Since the knowledge of modelling in the field of natural phenomena and related laws has advanced a lot, many approximate models have been made for such phenomena, and the effectiveness of these models is evident and provable due to the continuous progress in engineering and physics sciences [17,18]. However, the natural human world is less presented in the form of a model due to the complexities of human behaviour. Also, human systems are much more dynamic and complex than the natural world and do not have a stable state. This causes the complexity and uncertainty of human issues more and more. To decide on how to model them, key factors, rules of behaviour of agents, how agents interact with each other and with the environment, and such issues must be considered [19].

In ABM, computational modelling is done from the bottom up. ABM involves representing individuals in a complex adaptive system as discrete agents interacting autonomously in a simulated space to produce emergent and non-intuitive outcomes at the population level [20]. Agents interact or communicate based on predefined "rules" [21]. As the rules that govern agents' behavior influence results, it is imperative to tightly couple all rule-based algorithms throughout the model development process. In addition to other programming languages (such as C, Java, and Python), ABM can be implemented using specialized toolkits such as NetLogo, Swarm, or Repast. ABM is generally based on incremental modeling, starting with a simple model and progressing to more complex models [22].

SDs use loops, stores and flows to model the behaviour of complex systems over time and deal with internal causal loops and time delays that affect the behaviour of the entire system; it is an approach for modelling and simulating systems using ordinary differential equations [23]. ABM refers to modelling in which a dynamic process of interactions between agents is simulated repeatedly over time, similar to what is used in SD and discrete event modelling or other types of simulation methods that happen traditionally [24,25]. The SDs have many problems, and the ABMs should help to solve these problems; although this does not mean that SD is weaker than the ABM, perhaps the SD is much more mature than the ABM, which is still in its early stages [15,26]. The comparison with more details of the two methods is shown in Figure 1. As shown in Figure 1, the main difference between the two methods is in the level of modelling and perspective, which is macro and top-down for SD, but in ABM, they are micro and bottom-up.

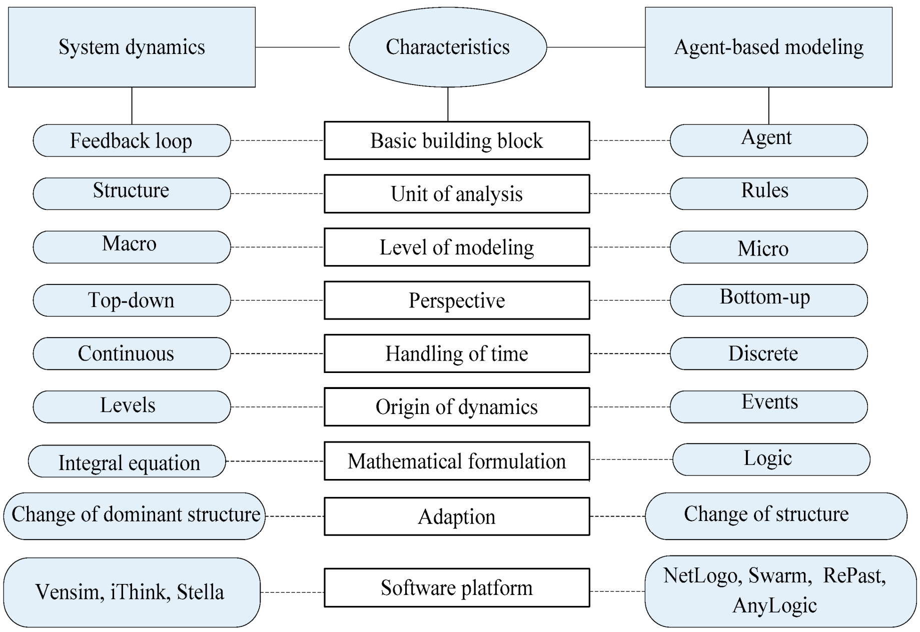

Figure 1. The comparison between SD and ABM [27].

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The application of ABMs in natural resource sciences was first studied by Bousquet et al. on managing renewable resources. In the mentioned study, a multi-agent simulator was created to better understand the interaction between users and natural resources [28]. Also, Balmann used these models in the field of managing agricultural operations. The research mentioned above focused more on the economic aspects of agriculture, and the most significant financial benefit for farmers was considered [29]. Becu et al. conducted a study in the field of ABM for water management in the catchment area in southern Thailand. For this purpose, they prepared an agent-based model, CATCHSCAPE, and investigated economic scenarios, land use and water resource management [30]. Linkola et al. developed an ABM for drinking water management, and their research showed that by using ABMs, results can be obtained that are difficult to achieve using methods such as SDs and other models [31]. In the field of water quality in the catchment area under the influence of agricultural pollution in a region, a study has been conducted using ABMs, the results of which showed that changing the behaviour of farmers is influential on the prediction and decision-making of other farmers, and the results of the agents' reactions on Water sources are different [32].

In this paper, we present a framework for agricultural demand that relies on farmers' socioeconomic characteristics to drive demand. This method exploits the heterogeneity of farmers with respect to age, income, education level, risk-taking, and the maintenance and updating of their memories. Psychological studies of agricultural systems are used to illustrate socioeconomic characteristics of farmers [33–36]. In the materials and methods section, the general framework of the proposed model is presented, and then two hypothetical scenarios are implemented by this model. Since the number of parameters introduced in the materials and methods section is large, all parameters are given in the abbreviation section along with the corresponding unit.

2. Materials and Methods

Agents involved in this research include farmers and reservoir operators. The decisions that farmers make according to their objective (here is to maximize the profit received from the sale of their products) change the water demand and force the reservoir operator to release according to the water demand. In this study, allocation is based on SOP (Standard Operating Policy). The decisions that farmers make based on their background and circumstances are explained in the following sections.

2.1. Farmers' Features

The farmers' decision to select the type of cultivation is influenced by various factors, with age and level of education being considered significant determinants [37–39]. Based on studies on agricultural risk [33,34,36,40], the parameter is defined as Equation (1), which shows the level of risk-taking of farmers.

$$\alpha_i^y = \frac{\sqrt{\left(Max_{age} - age_i^y\right)^2 + (100 - AID_i)^2}}{\sqrt{\left(Max_{age} - Min_{age}\right)^2 + (100 - 0)^2}} \tag{1}$$

2.2. Neighbourhood

Farmers' decisions affect each other. To limit the impact of other farmers' decisions on a farmer, a neighbourhood, according to Figure 2, is considered for each field (or farmer). The reason for the maximum distance of 6 meters in Figure 2 is that the farmers' land may be partially connected, and the access road is located between them. As shown in Figure 1, polygons 7, 8, 12, 14, 17, and 18 are neighbors around farmer 13. The NF parameter is defined as the number of farmers neighbours a farmer.

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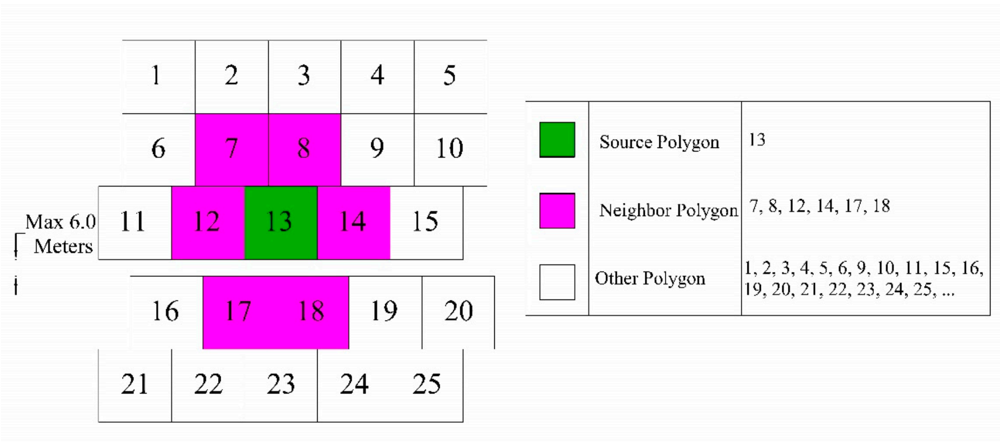

Figure 2. Definition of neighbourhood for a farmer.

2.3. Farmers' Decisions

In this study, farmers can make three choices: changing the cropping pattern and the cultivation date and improving the irrigation technology. These choices are among the Farmers' features, as explained in the previous sections.

2.4. Formulation

According to [41], Ω1, Ω2, Ω3 and Ω4 (Equations (2)–(5)) are the parameters that determine what choices the farmer makes in the short and long term based on their past decisions. Their neighbours influence the decisions that each farmer makes. Therefore, a set of neighbours is considered for each farmer. The initial conditions for farmers remain unchanged for the first five years in the model, with modifications being implemented from the fifth year onwards.

$$\Omega_{1,i}^{y} = sign\left(\max\left(0, \frac{P_i^{y-1}}{\frac{\sum_{i=1}^{NF_i} P_i^{y-1}}{NF_i}} \right) \right) \quad \forall y > 5 \tag{2}$$

$$\Omega_{2,i}^{y} = sign\left(\max\left(0, \frac{\sum_{y-5}^{y-1} P_i^{y}}{\frac{\sum_{y-5}^{y-1} \sum_{i=1}^{NF_i} P_i^{y-1}}{NF_i}} \right) \right) \quad \forall y > 5 \tag{3}$$

The economic evaluation of short-term and long-term decisions made by individual farmers in comparison to their neighbours is demonstrated by Ω1 and Ω2, respectively. If a farmer has earned more profit than their neighbours in the past five years, Ω1 (or Ω2) is assigned a value of 1. Otherwise, it is set to a value of zero.

$$\Omega_{3,i}^{y} = sign\left(\max\left(0, \frac{wa_i^{y-1}/wp_i^{y-1}}{\sum_{y-5}^{y-1}(wa_i^{y-1}/wp_i^{y-1})/5} \right) \right) \quad \forall y > 5 \tag{4}$$

$$\Omega_{5,i}^{y} = sign\left(\max\left(0, \frac{\sum_{i=1}^{NF_i}(wa_i^{y-1}/wp_i^{y-1})}{\sum_{y-5}^{y-1}\sum_{i=1}^{NF_i}(wa_i^{y-1}/wp_i^{y-1})/5} \right) \right) \quad \forall y > 5 \tag{5}$$

Ω3 (Ω4) denotes the evaluation regarding the precision of their short-term water estimation concerning their long-term estimations. To illustrate, if the ratio of requested water to available water for each farmer is lower than the corresponding ratio observed in the past five years, Ω3 (Ω4) is

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assigned a value of 1; otherwise, it is assigned a value of zero. wa_i^y and wp_i^y calculate based on Equations (6)–(8).

$$FS_i^{y,m} = A_i \times \frac{RH_i^{y,m}}{\sum A_i} \tag{6}$$

$$wa_i^y = \sum_{M=sm}^{cm} \eta_i^y \times FS_i^{y,M} \tag{7}$$

$$wp_i^y = \sum_{M=sm}^{cm} CD_i^{y,M} \tag{8}$$

The actual yield value (Ya) is obtained based on Equation (9), where Ky and Yp are yield response factor and potential yield (ton/ha), respectively.

$$1 - \frac{Y_a}{Y_p} = K_y \times (1 - \frac{wa}{wp}) \tag{9}$$

The profit of each farmer in the yth year is obtained according to Equation (10), which is equal to the income from the sale of products minus the costs, including the costs of planting and irrigation and, harvesting and changing the irrigation technology if necessary.

$$P_i^y = \sum_{c=1}^{Crop\ Numbers} [(Y_{a_{c_i}}^y \times A_{c_i}{}^y \times 1000 \times S_{c_i}{}^y) - (A_{c_i}{}^y \times C_{c_i}{}^y)] - ITC_i^y \tag{10}$$

2.4.1. Changing the Cropping Pattern

The calculation of the summation of Ω values, denoted as $\sum \Omega_i^y$, determines whether a farmer's demand for water would exceed the average available amount. The violation rate, referred to as β (Equation (11)), represents the farmer's perception of the water quantity at their disposal [42].

$$\beta_i^y = \begin{cases} \alpha_i^y & \forall \alpha_i^y & If \sum \Omega_i^y = 4 \\ \alpha_i^y - 0.3 & \forall \alpha_i^y > 0.3 & If \sum \Omega_i^y = 3 \\ \alpha_i^y - 0.5 & \forall \alpha_i^y > 0.5 & If \sum \Omega_i^y = 2 \\ \alpha_i^y - 0.7 & \forall \alpha_i^y > 0.7 & If \sum \Omega_i^y = 1 \\ 0 & \forall \alpha_i^y & If \sum \Omega_i^y = 0 \\ 0 & & else \end{cases} \tag{11}$$

The amount of water expected by each farmer ($EW_i{}^y$) is obtained from Equation (12). In this article, the amount of water rights for each land is given based on its area (Ai) (so this equation can be changed according to the way water is distributed among farmers). In this equation, the amount of water released in each month is shown by the parameter ($RH_i^{Y,m}$) and the irrigation efficiency in each year for each farmer is shown by the symbol (η_i^y).

$$EW_i{}^y = A_i \frac{\frac{\sum_{Y=y-5}^{y-1} \sum_{m=1}^{12} RH_i^{Y,m}}{5}}{\sum A_i} \times (1 + \beta_i^y) \times \eta_i^y \qquad \forall y > 5 \tag{12}$$

The method of changing the planting date or changing the planting pattern is that no farmer changes his planting date or pattern in the first 5 years. In the following years, β_i^y, wa_i^y, P_i^y are calculated based on the last 5 years. Then the expected water ($EW_i{}^y$) is calculated based on Equation (12) and the farmer decides according to it what cropping pattern and date to have, and this choice is based on maximizing the profit of each farmer in the same year (Maximizing Equation (10)).

2.4.2. Installing New Irrigation Technology

Creating new ideas in a group of people is a step-by-step process. This means learning about the new thing, what you think about it, deciding what to do, making it happen, and ensuring it works [43]. In the search phase to obtain information about new irrigation technology, alpha parameters, education level and water deficit in the last 5 years are suggested. According to Table 1, if the amount of water deficit in the last 5 years is more than the limit presented in the table (δ1-δ8), the farmer will seek information about new irrigation technology.

Table 1. Thresholds for obtaining knowledge about new irrigation technology.

	$0 \le \alpha_i^y \le 0.3$	$0.3 < \alpha_i^y \le 0.5$	$0.5 < \alpha_i^y \le 0.7$	$0.7 < \alpha_i^y \le 1$
High Educated Farmer	δ1	δ2	δ3	δ4
Low Educated Farmer	δ5	δ6	δ7	δ8

To simplify the problem, the next step after acquiring knowledge is to decide on the use of new irrigation technology (Table 2). The items in the table + mean the farmer's decision to use the new irrigation technology.

Table 2. Decide for using new irrigation technology.

	$0 \le \alpha_i^y \le 0.3$	$0.3 < \alpha_i^y \le 0.5$	$0.5 < \alpha_i^y \le 0.7$	$0.7 < \alpha_i^y \le 1$
High Educated Farmer	-	0	+	+
Low Educated Farmer	-	-	0	+

The flowchart of the proposed model is shown in Figure 3. As is evident in the figure, at the end, the profit and the amount of agricultural demand in the studied period can be calculated. The ABM simulator shown in the middle of the flowchart determines how agricultural demand will change each year.

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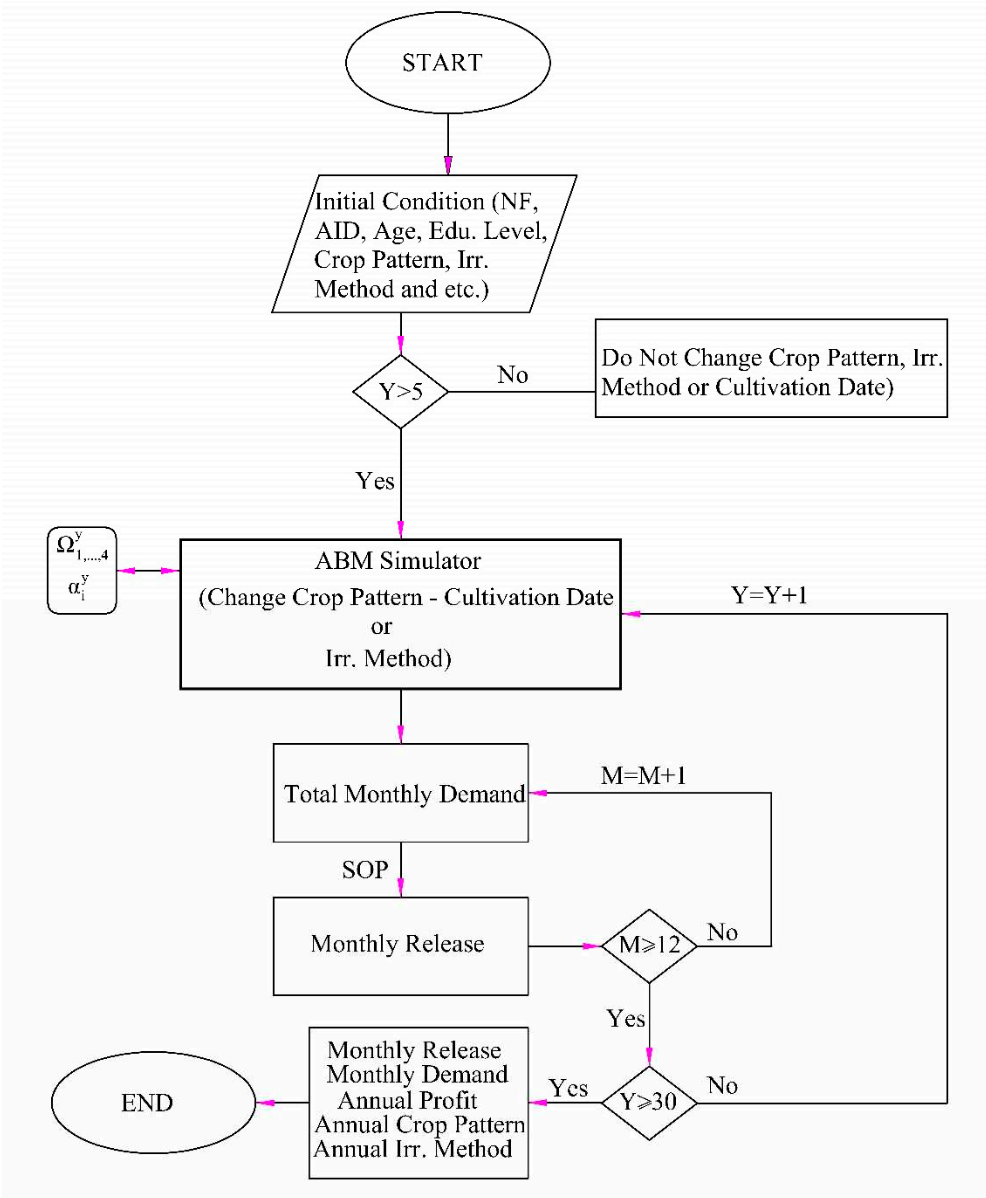

Figure 3. The Proposed ABM Flowchart.

2.5. Model testing

The hypothetical study area includes 30,000 hectares of agricultural land, which is equally divided among 15 farmers with different ages and educational characteristics. Figure 4 shows the initial agricultural lands site plan. The dominant cultivation in this area is assumed to include four crops: wheat, barley, cucumber and tomato. At first, it is assumed that every 15 farmers cultivate all four crops equally. The characteristics of the 15 farmers considered in this section are given in Table 3. The α parameter, which is the main foundation of this study, was tried to be completely scattered.

β was considered 0.6 for the old irrigation technology and 0.8 for the new technology and ITC was considered 14 million dollars for each land. Also, the values of $\delta 1$ to $\delta 4$ were considered 30, 25, 20 and 15, and $\delta 5$ to $\delta 8$ 35, 30, 25, 20, respectively. Crops agronomic characteristics (CD (m3/ha), Yp (ton/ha), Ky) and cost and sale of products (Cc (($/ha)) and Sc ($/Kg)) were given from our last published research, which was done downstream of the Karaj reservoir dam. In this study, bringing forward and postponing the cultivation date was considered 7, 14, 21, and 28 days [44].

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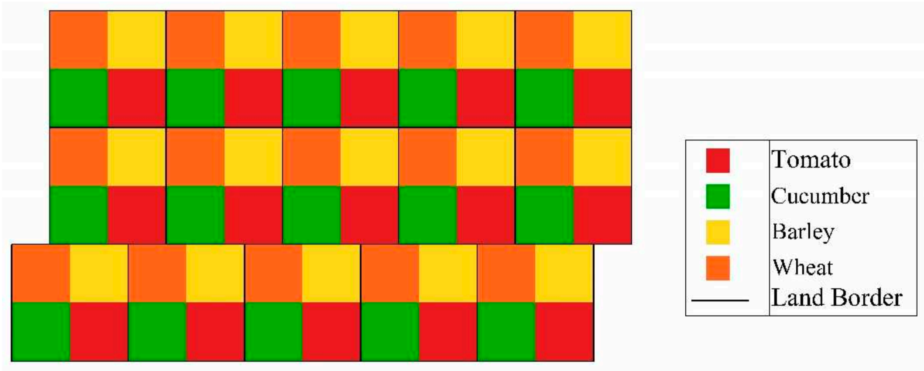

Figure 4. Initial agricultural lands site plan.

Table 3. Characteristics of the farmers.

Farmer ID	Age	AID (%)	Edu. Level	α
1	24	15	H	0.85
2	36	35	H	0.64
3	55	85	L	0.15
4	60	45	L	0.51
5	18	55	L	0.57
6	45	45	H	0.53
7	30	35	L	0.66
8	20	30	H	0.74
9	19	20	L	0.83
10	42	80	L	0.25
11	38	40	H	0.59
12	25	25	L	0.76
13	55	70	L	0.28
14	45	65	H	0.35
15	55	80	L	0.19

The defined problem was investigated in two scenarios. In ABM1, all agricultural lands affect each other (neighbourhood has no meaning in this scenario), and in the second scenario (ABM2), the neighbourhood was defined according to what was specified in section 2-2. In the second scenario, the model for 15! (1,307,674,368,000 cases) were implemented for 20 years. The results of the two scenarios are fully presented in the results section

3. Results

3.1. ABM1 Scenario

In the first scenario, the neighbourhood concept is nonexistent, and all farmers influence each other. In the initial five years, the agricultural demand remained constant. From the sixth year onwards, the ABM begins to alter the decisions of the farmers and calculate agricultural demands. Figure 5 illustrates the agricultural demand and the volume of the hypothetical incoming flow over 30 years. As depicted in Figure 5, the amount of agriculture remains at 2307 MCM for the first five years. From the sixth year, farmers decide to enhance their profits by changing the crop pattern, adjusting the cultivation dates, or upgrading the irrigation system to meet their requirements better. In dry years, such as the 24th year, farmers make protective decisions that reduce water demand. Conversely, in wet years, their choices lead to increased water demand. The chart related to the first scenario demonstrates stability in agricultural demand for the initial five years, which is consistent with the unchanged decisions of the farmers during this period. From the sixth year onwards, changes in the decisions of the farmers begin to manifest in the chart. In dry years, like the 24th year, a noticeable reduction in agricultural water demand is due to the protective decisions made by the farmers. In contrast, in wet years, there is an increase in water demand, indicating changes in planting patterns and increased utilization of water resources. These variations highlight the sensitivity of farmers' decisions to the environmental climatic and hydrological conditions, directly impacting agricultural water demand.

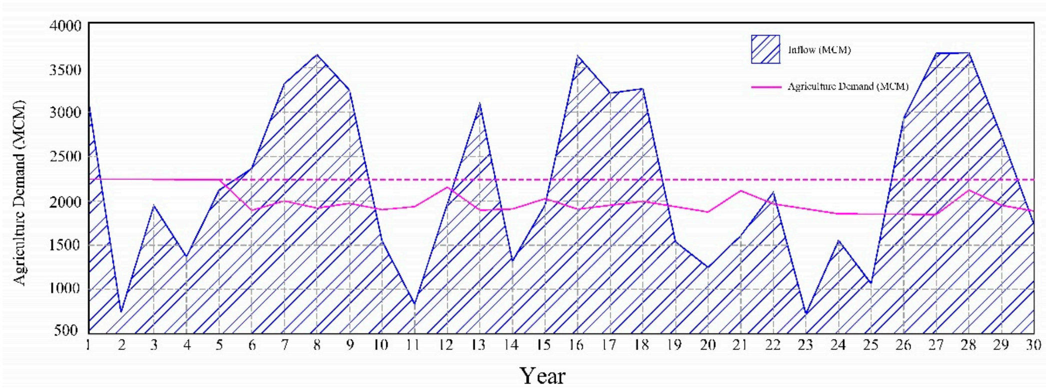

Figure 5. Agricultural demand fluctuations in ABM1 Scenario.

Figure 6 illustrates a comparative analysis of deficit water amounts under different scenarios. In the first scenario, where dynamic changes in agricultural demands are con-sidered, the model shows a lower amount of deficit water compared to the scenario where agricultural demand is held constant. A notable observation is the significant difference in deficit water amounts during the 20th and 25th years of modeling, corresponding to the dry years. This indicates that considering dynamic agricultural demands, influenced by various factors such as climatic conditions, leads to a more adaptable and resilient agri-cultural system, better equipped to manage water resources during dry periods. The mod-el suggests that adaptive strategies, such as changing cropping patterns and irrigation systems in response to varying environmental conditions, play a crucial role in optimiz-ing water use and reducing deficit, particularly in dry years.

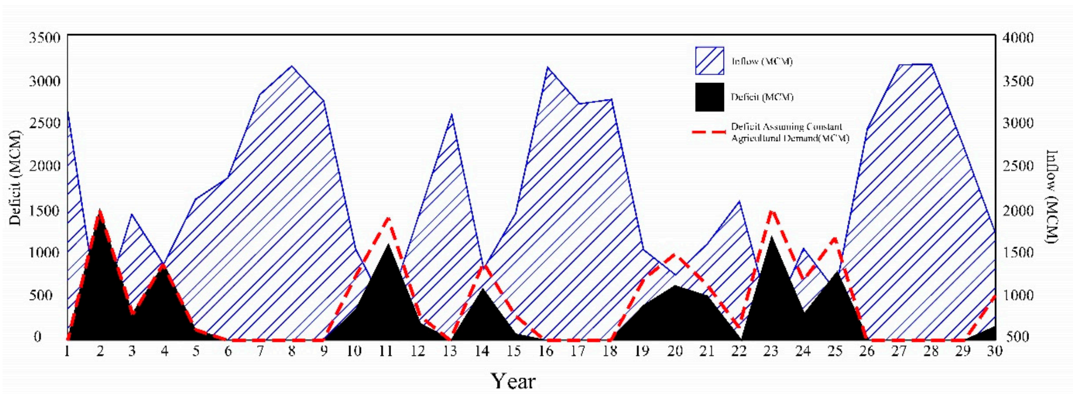

Figure 6. Deficit fluctuations in ABM1 Scenario and constant agriculture demand case.

Figure 7 delineates the annual profits, presented in millions of dollars, under differ-ent modeling scenarios. In the ABM1 scenario, where the agricultural demand is dynam-ically adjusted, an average annual profit of 3109 million dollars is observed. This signifies a substantial increase of about 1100 million dollars compared to the scenario where the agricultural demand is considered constant. A distinct trend is evident in the ABM1 sce-nario, where the annual profit exhibits variations in alignment with the inflow to the res-ervoir, albeit with a slight lag. This synchronization underscores

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the direct influence of water availability on agricultural profitability. In this adaptive model, the annual profit oscillates between 1875 and 4150 million dollars, reflecting the flexibility and responsive-ness of the agricultural system to fluctuating water inflows and demonstrating the eco-nomic advantage of an adaptable agricultural demand in optimizing profit outcomes.

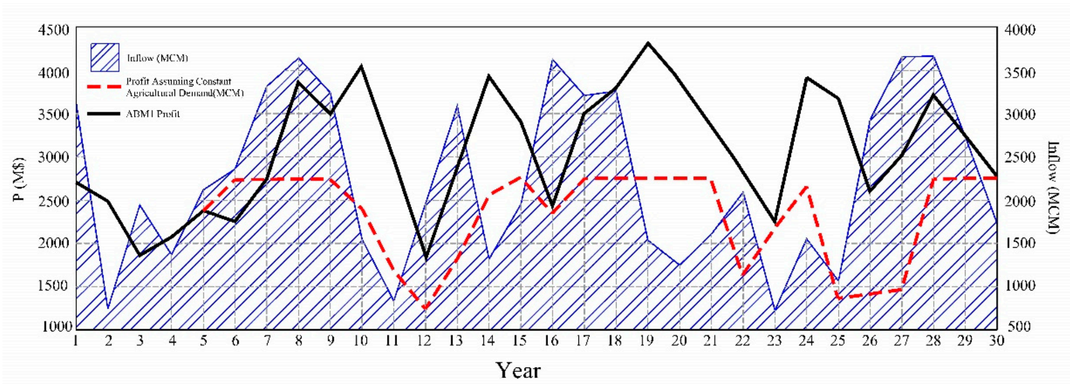

Figure 7. Profit fluctuations in ABM1 Scenario and constant agriculture demand case.

Figure 8 elucidates the relationship between the average annual profit and the risk-taking parameter (α) at a micro-level, focusing on individual agents or farmers. The figure conspicuously reveals that a higher value of α, indicative of a greater propensity for risk-taking, correlates with diminished average profits. Farmers exhibiting a higher risk appetite tend to adopt novel irrigation technologies, seeking to optimize their agricultural practices. However, such technologies, while innovative, may inadvertently lead farmers to overestimate their available water resources, thereby affecting their decision-making and overall profitability adversely. The utilization of riskier strategies, such as the adoption of new technologies, may not always translate into enhanced profits or optimized resource use, as corroborated by an FAO study [40]. Hence, while risk-taking can sometimes be conducive to exploring innovative approaches and technologies in agriculture, it necessitates a nuanced and meticulous strategy to ensure that it contributes positively to the farmers' profitability and sustainable resource management.

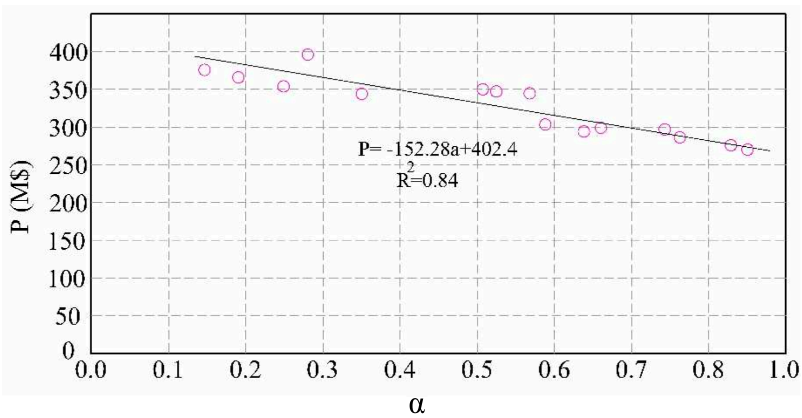

Figure 8. Farmers' profit diagram in terms of α (level of risk-taking of farmers).

3.2. ABM2 Scenario

In this scenario, unlike the ABM1 scenario, the neighbourhood makes sense. So, model for 15! cases were examined for 30 years. The maximum and minimum band of the total water demands of farmers was calculated each year, as shown in Figure 9. The water requirement in scenario 1 is in this band in most year.

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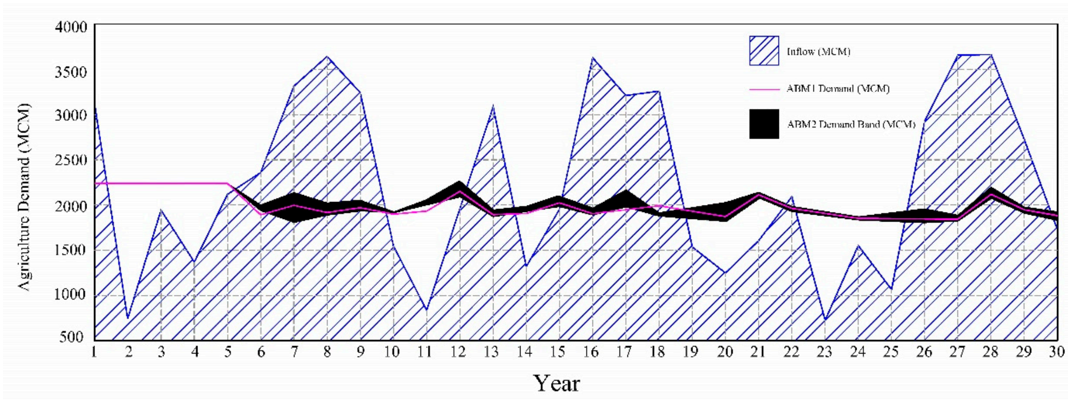

Figure 9. Agricultural demand band in ABM2 Scenario.

The most important reason for introducing scenario 2 is to investigate the effect of the neighbourhood on the profit of each agent. For further investigation, the agents were divided into three categories according to the α parameter: (0-0.3), (0.3-0.7) and (0.7-1). The average parameter α in the neighbourhood of each agent is also divided according to the categories above. The amount of profit obtained from each state was calculated, and a matrix was formed, which is presented in Figure 10. In this scenario, as in scenario 1, the agents with a higher α parameter and whose neighbourhood has a higher alpha get less profit.

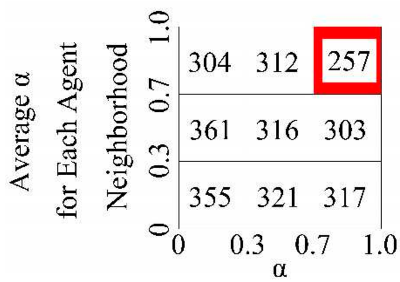

Figure 10. Matrix of profit (M$) based on α parameter.

4. Discussion and Conclusions

The purpose of this study was to introduce and create a relatively realistic model based on the socio-economic characteristics of farmers, which changes the water demand based on the existing conditions. To use the available volumes, the SOP rule was used, which is a common law in the use of dam reservoirs, which is used by operators and legislators of water resources. Legislators always try to determine the volume of release each year in such a way as to reduce the volume of deficit to the minimum possible amount. Recently, other Indexes have been presented regarding the performance of the dam reservoir, such as the Reliability Index and Vulnerability Index [12,45,46]. But, most of the conventional views are based on the top-down approach. To optimize the demand, different functions are introduced that can optimize the cultivation pattern or maximize the profit, which are single or multi-objective functions. In none of the conventional models, the needs, including drinking needs, industry, agriculture, and the environment, have yet to be combined as combined agents with the dam reservoir operation models.

In this study, the objective function was to maximize the farmers' profit, which changed based on the situation and conditions in which the farmers were placed. In this study, the parameters that changed farmers' behaviour (or agricultural water demand) were age, level of education, and income dependence on agriculture. For simplicity, it was assumed that the last two parameters remained constant over time. Two scenarios were studied to investigate the effect of each agent's neighbourhood. In the first scenario (ABM1), the deficit volume was reduced by about 35% compared to the steady state of assuming agricultural needs. Also, the farmers earned more profit (about 20%).

Investigations of parameter α (risk-taking level) in the first scenario showed that farmers (agents) with higher α earn less profit compared to other agents. In the second scenario (ABM2), where all the placement states of farmers (15! cases) were investigated, it showed that farmers with higher α in the neighbourhood of agents with higher average α earn less profit on average during the simulation period, which is which was consistent with the results of [40]'s study.

This study underscores the significant impacts that socio-economic characteristics and risk-taking behaviors of farmers have on agricultural water demand. Through agent-based modeling, we were successful in examining the influence of these factors within a dynamic and interactive system. Additionally, this study emphasizes that considering neighbourhood influences and interactions among farmers can offer valuable insights into decision-making and policy formulation related to agricultural water management.

For future studies and continuation of this research, the following are suggested:

- Exploration of alternative water resource utilization strategies beyond the SOP, such as the Hedging Rule (HR)
- Expansion of the ABM frameworks to encompass other water demands like domestic and industrial demands, facilitating a comprehensive multi-agent modeling approach
- The inflow model of a dam (with dead volume and maximum storage volume) can be modelled.
- Consideration of additional factors influencing water consumption, such as fertilization timing and types, and the implementation of deficit irrigation strategies, could be integrated into future models.

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Abbreviations

i	Index of farmer
y	Index of year
m	Index of month
α_i	Level of risk-taking of farmers
Max_{age}	Maximum age among farmers in the region (year)
Min_{age}	Maximum age among farmers in the region (year)
age_i^y	The age of the ith farmer yth year (year)
AID	The percentage of annual income dependence on agriculture (%)
NF_i	The number of farmers in the neighborhood of ith farmer
$\Omega_{1..4,i}^y$	Binary parameters of ith farmer in yth year
P_i	Profit of the ith farmer ($)
Wa	Actual available water to farmer (m^3/ha)
Wp	potential water demand by plants (m^3/ha)
FS_i	Water share for each farmer (MCM)
RH_i	The amount of water released from the reservoir (MCM)
sm and em	the first and last months of crop growth
η	Irrigation efficiency
CD	Monthly water requirement of each crop (m^3/ha)
Y_a	The actual yield (ton/ha)
Y_p	The potential yield (ton/ha)
K_y	Yield response factor
S_c	The sales price of the cth crop ($/Kg)
C_c	The cost of planting, harvesting and preparation of cth crop ($/ha)
ITC	The installation cost of new irrigation technology ($)

$\sum \Omega_i^y$	Summation of Ω values
β	The violation rate
EW_i^y	The expected water for ith farmer in yth year
$\delta_1, \ldots, \delta_8$	Thresholds for obtaining knowledge (%)

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